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**HYDRAULIC CONDUCTIVITY AND OTHER PHYSICAL
CHARACTERISTICS OF SOME "WET" SOILS IN
SOUTHWESTERN MINNESOTA**

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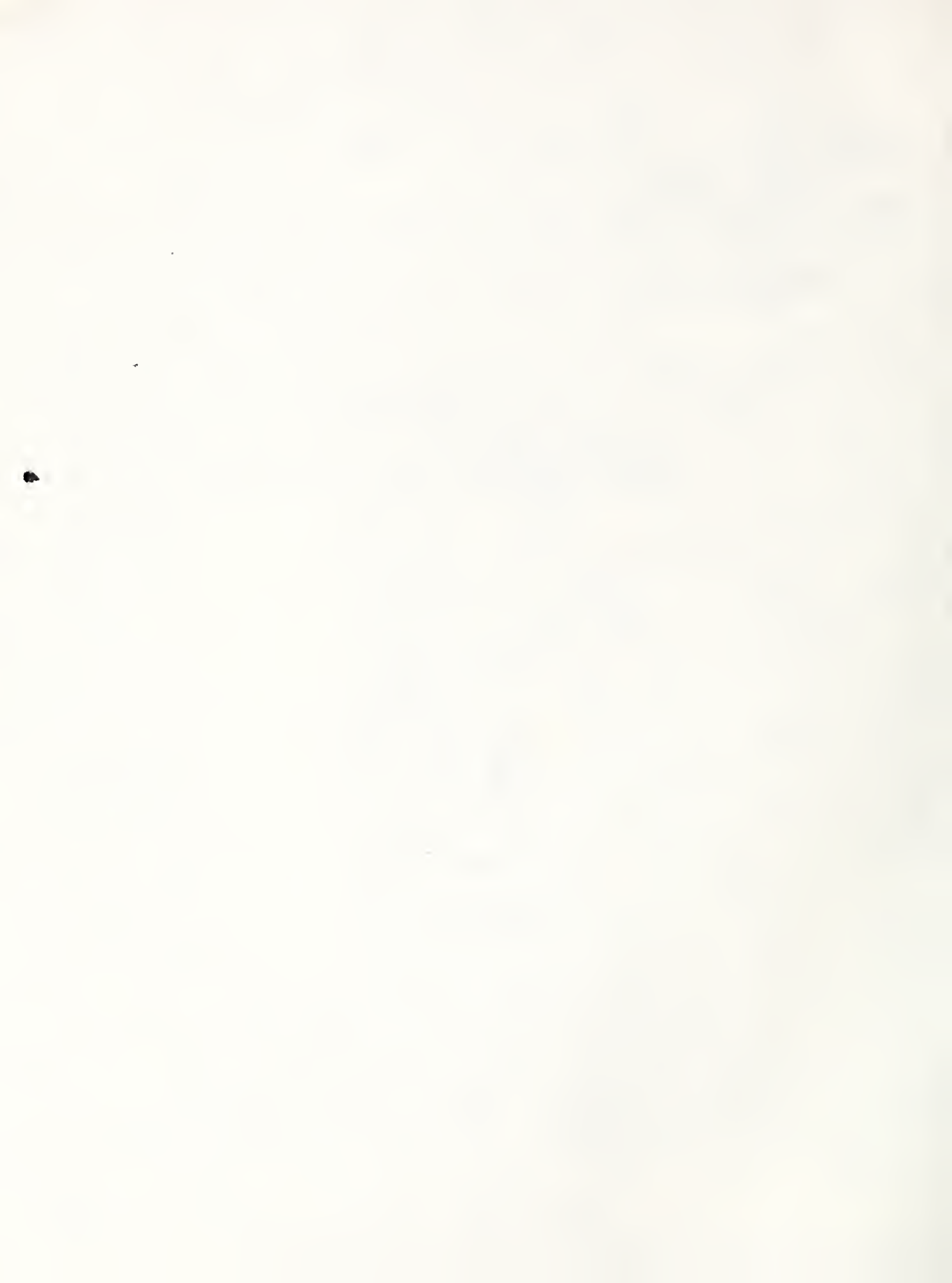
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HYDRAULIC CONDUCTIVITY AND OTHER PHYSICAL CHARACTERISTICS OF SOME "WET" SOILS IN SOUTHWESTERN MINNESOTA¹

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INTRODUCTION

"Wet" soils are frequently found in the numerous shallow depressional areas in southwestern Minnesota. These "wet" areas range in size from a few acres to a square mile or more. During the past 50 years, open ditches and tile lines have been installed to serve as outlets for excess water from many of these wet areas.

This study was made to compare some of the drainage characteristics of the soils in these depressional areas for use in determining tile and surface drainage requirements.

AREA OF INVESTIGATION

Tests were conducted on soils from 11 sites representing most of the major "wet" soils in the area. The sites were located in Lincoln, Yellow Medicine, and Lac qui Parle Counties. The soils that were mapped had very slow to moderate drainage.

SAMPLING PROCEDURE

At each sampling site, borings were made and the depths of the various horizons in the profile were determined. Soil samples for the various tests were obtained near the middle depth of each horizon. Where the horizon extended more than 2 feet in depth, two samples were obtained. Soil cores 3 inches in diameter and 3 inches long were obtained with a soil sampler and were placed in aluminum cylinders³. These soil cores were used to measure hydraulic conductivity and bulk density. After removal, the core samples were immediately placed in waterproof containers to prevent the loss of moisture. Three sets of samples were obtained at each site. Disturbed bulk soil samples were used for particle size analysis, moisture retention characteristics, and available water determinations.

¹ Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, in cooperation with the Soil Conservation Service, U.S. Department of Agriculture, and the Minnesota Agricultural Experiment Station.

² Agricultural engineer, Agricultural Research Service, USDA, at Morris, Minn. Acknowledgment is made to A. S. Robertson, State soil scientist; G. A. Simpson, area conservationist; and Hilding Hokanson, of the Soil Conservation Service for their assistance in locating the sample sites and preparing profile descriptions.

³ Uhland, R. E. Physical properties of soils as modified by crops and management. Soil Sci. Soc. Amer. Proc. 14: 361-366, 1949.

TESTING PROCEDURE

Hydraulic conductivity rates were determined on the basis of the rate of downward flow of water through saturated samples, with water and room temperatures at $70^{\circ} \pm 1.0^{\circ}$ F. Core samples were saturated under vacuum by supplying water to the lower surface. Tests were conducted with a water head of $2\frac{1}{2}$ inches.

Bulk density, based on the oven-dry weight, was expressed as a ratio of oven-dry weight of soil to volume of soil sample at time of sampling.

The amount of water in these soils available for plant use was taken as the difference between field capacity and wilting percentage. The water content of the saturated soil, after it had been subjected to a suction of $\frac{1}{3}$ bar, or about 5 pounds per square inch, was taken as field capacity. For the wilting percentage, a suction of 15 bars, or about 225 pounds per square inch, was used. The water content of the soil, on a dry-weight basis, was estimated at various suction levels by a laboratory procedure using a pressure plate apparatus⁴. Water content values were converted from a weight base to a volume basis by multiplying the values by the bulk density.

The mechanical analyses of the soil were made by a standard hydrometer method⁵. Particles smaller than 5 microns in diameter were considered clay, particles 5 to 50 microns in diameter were considered silt, and larger particles were considered sand.

RESULTS

Figure 1 shows hydraulic conductivity values by horizons for 11 different soils in southwestern Minnesota. Values ranged from 0.01 inch per hour (very slow) to 22.2 inches per hour (very rapid). The soils are shown in decreasing order of the hydraulic conductivity values for the most restrictive horizon of the profiles; except some consideration was given to the depth of the restrictive horizon. The horizon of a profile with the lowest hydraulic conductivity value largely determines the rate of water movement through the soil irrespective of the hydraulic conductivity value of the remaining horizons. However, the depth of the most restrictive horizon also has an effect on the "wetness" of a soil. A soil with a restrictive horizon near the surface will be "wetter" than a similar soil with a restrictive horizon at the 4- or 5-foot depth. For example, the Parnell silty clay loams in Yellow Medicine County and in Lincoln County had minimum hydraulic conductivity values of about 0.8 inch per hour for a single horizon. At the Yellow Medicine County site, the restrictive horizon was at about the 5-foot depth, but at the Lincoln County site the restrictive horizon was from the surface to 15 inches in depth. Thus, the soil with the restrictive horizon near the surface would be wetter than the soil with the restrictive horizon at a 5-foot depth even though their minimum hydraulic conductivity values were about the same. A restrictive horizon near the surface is generally more affected by cultural practices and plant growth.

Soil profile descriptions, hydraulic conductivities, and soil moisture retention data for the 11 sites are presented in the appendix. The range of hydraulic conductivity values, as well as the average values, are reported for each horizon⁶ for each soil. Definite differences and considerable ranges in hydraulic conductivity values are noted for the several horizons of a single soil and also between the different soils. The hydraulic conductivity values provide useful comparisons to be made of drainage characteristics of these soils. However, since the hydraulic

⁴ Richards, L. A. Pressure-membrane apparatus--construction and use. *Agr. Engin.* 28: 451-454. 1947.

⁵ Day, Paul R. Report of the Committee on Physical Analyses, 1954-55, Soil Conservation Society of America. *Soil Sci. Soc. Amer. Proc.* 20: 167-168. 1956.

⁶ U.S. Soil Conservation Service. Soil Classification, A Comprehensive System, 7th Approximation. (Chapter 5, Culture of Classification in the Higher Categories Subgroup, Great Group, Suborder, and Order) 265 pp. August 1960, Amended June 1964.

Sites

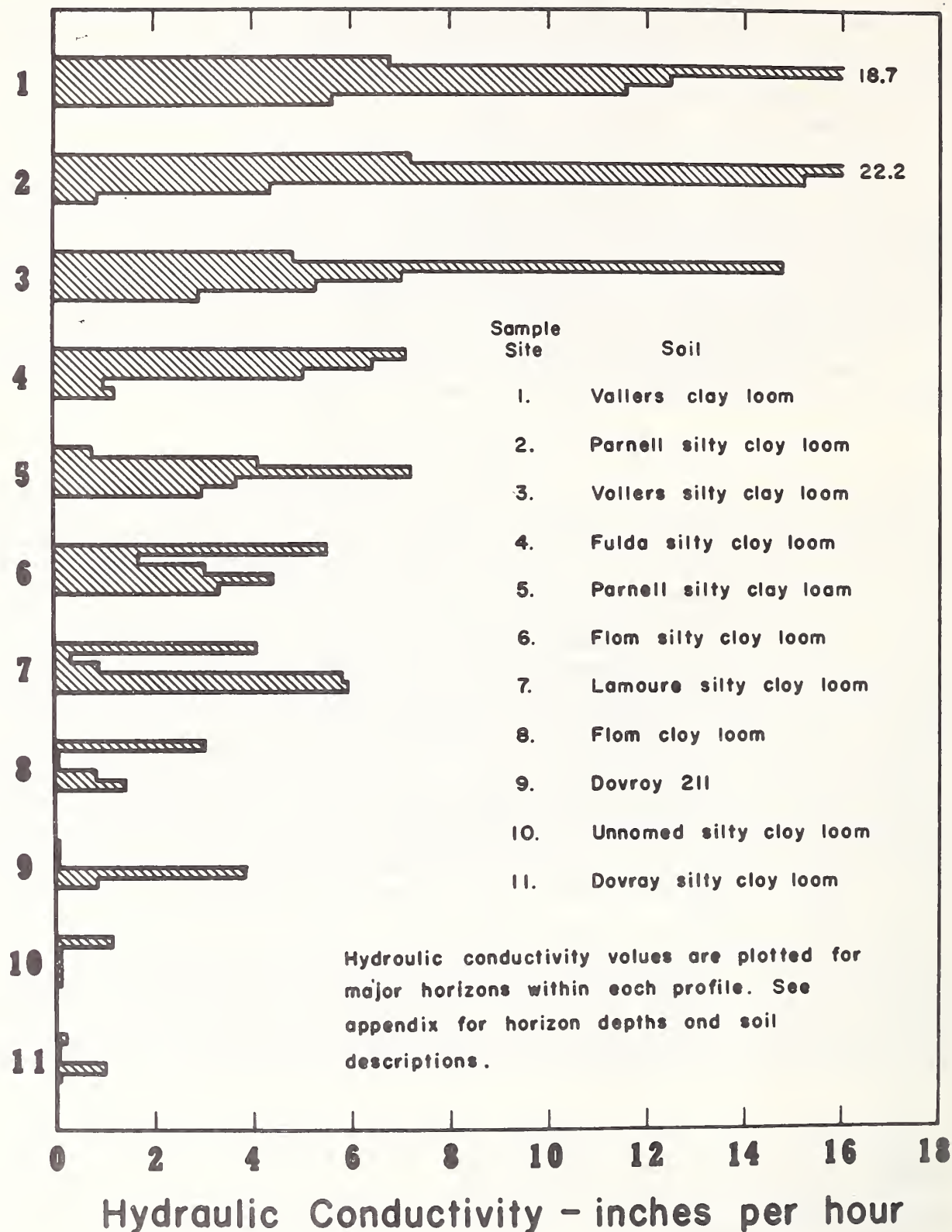


Figure 1.--Hydraulic conductivity of some "wet" soils in southwestern Minnesota.

conductivity values are based on uniform laboratory tests made on core samples rather than on direct measurements of water movement through the soil in the field, they may not be absolute values of field hydraulic conductivity.

A detailed statistical study was made to determine if hydraulic conductivity could be reliably predicted on the basis of bulk density, moisture-holding capacity or amount of sand, silt or clay. Hydraulic conductivity was first correlated with each of the factors. The logarithm of the hydraulic conductivity was then correlated with the three best factors and also with various combinations of factors.

The relation of hydraulic conductivity to several other soil properties for 165 samples are given below:

For hydraulic conductivity¹ versus moisture content (M)² at 0.1-bar suction:

$$\text{Log HC} = 2.89 \text{ minus } 0.071 \text{ M}; \quad r = 0.63$$

$$\text{HC} = 15.63 \text{ minus } .28 \text{ M}; \quad r = .42$$

For hydraulic conductivity¹ versus moisture content (M)² at 15-bar suction:

$$\text{Log HC} = 1.87 \text{ minus } 0.105 \text{ M}; \quad r = 0.61$$

$$\text{HC} = 11.03 \text{ minus } .374 \text{ M}; \quad r = .37$$

For hydraulic conductivity¹ versus clay content (C)³:

$$\text{Log HC} = 1.89 \text{ minus } 0.045 \text{ C}; \quad r = 0.56$$

$$\text{HC} = 9.74 \text{ minus } .129 \text{ C}; \quad r = .28$$

For hydraulic conductivity¹ versus sand content (Sa)⁴:

$$\text{HC} = 0.64 \text{ plus } 0.133 \text{ (Sa)}; \quad r = 0.28$$

For hydraulic conductivity¹ versus bulk density (B)⁵:

$$\text{HC} = 11.4 \text{ minus } 5.49 \text{ B}; \quad r = 0.14$$

For hydraulic conductivity¹ versus silt content (Si)⁶:

$$\text{HC} = 3.88 \text{ minus } 0.007 \text{ (Si)}; \quad r = 0.01$$

¹ Hydraulic conductivity, inches per hour.

² Moisture content, percent.

³ Clay content, percent.

⁴ Sand content, percent.

⁵ Bulk density, grams per cubic centimeter.

⁶ Silt content, percent.

The best correlation with a single factor was between the logarithm of the hydraulic conductivity and the moisture content at 0.1-bar suction. However, even this correlation was not significant at the 95-percent level. The next best correlation was with moisture content at 15-bar suction. The third best correlation was with the amount of clay in the soil. Neither the amount of silt or sand nor the bulk density was closely related to hydraulic conductivity. Only a slightly better correlation was found when hydraulic conductivity was compared with two or more factors rather than a single factor. All factors were more closely correlated to the logarithm of the hydraulic conductivity than to the value itself. The hydraulic conductivity values showed obvious differences in wetness between soil profiles, although individual measurements varied considerably.

The data in this report can be used as a guide for estimating the relative drainability of these soils. The hydraulic conductivity of these soils cannot be reliably predicted on the basis of bulk density, moisture-holding capacity, or mechanical analysis.

APPENDIX

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 1

Soil Type: Vallers clay loam

Location: In cropland 50 feet west of second electric pole north of $\frac{1}{4}$ corner in the SE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 9, T. 114 N., R. 43 W., Yellow Medicine County, Minn.

Parent Material: Glacial till of Mankato substage.

Classification: Calcium carbonate Solonchak.

Drainage: Poor.

Horizon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suction of--				Available water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	<u>In.</u>		<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./in.</u>	<u>G./cc.</u>	<u>In.</u>
A ₁ ca	0-8	Black (10YR 2/1) clay loam; cloddy; friable and sticky; contains a few white threads of calcium carbonate; violent effervescence; clear smooth boundary.	(2)	(2)	(2)	(2)	(2)	(2)	(2)	2.00
A ₃ ca	8-13	Very dark-gray (10YR 3/1) clay loam containing about 25 percent grayish-brown (2.5Y 5/2) worm casts; moderate, very fine subangular blocky structure; friable and sticky; violent effervescence; clear wavy boundary.	9-12	31.1	25.3	18.1	13.4	0.154	1.29	
C ₁ ca	13-21	Grayish-brown (2.5YR 5/2) clay loam containing about 25 percent very dark-gray (10YR 3/1) worm casts and a few fine faint light-olive-brown (2.5Y 5/6) mottles; weak, very fine and fine subangular blocky structure; friable; violent effervescence; clear wavy boundary.	15-18	26.2	21.8	15.7	9.8	.149	1.24	
C ₂ ca	21-30	Light-brownish-gray (2.5Y 6/2) clay loam containing common fine distinct yellowish-brown (10YR 5/8) mottles; very weak, fine and medium subangular blocky structure; friable; violent effervescence; gradual smooth boundary.	24-27	29.9	24.6	17.3	9.7	.204	1.37	1.84
C ₃ g	30-60	Light-olive-gray (5Y 6/2) clay loam containing common medium distinct yellowish-brown (10YR 5/8) mottles; structure not determined as horizon examined with soil auger; friable; strong effervescence.	33-36	33.0	26.5	18.1	9.7	.223	1.33	2.23
			45-48	32.7	25.5	17.0	11.9	.201	1.48	4.02

Horizon	Sample depth	Mechanical analyses				Hydraulic conductivity	
		Sand	Silt	Clay		Average	Range
	<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>		<u>In./hr.</u>	<u>In./hr.</u>
A ₁ ca	(2)	(2)	(2)	(2)		(2)	(2)
A ₃ ca	9-12	35.0	28.4	36.6		6.8	2.07- 9.32
C ₁ ca	15-18	31.2	26.3	42.5		18.7	10.81-26.40
C ₂ ca	24-27	35.3	28.3	36.4		12.5	5.34-26.14
C ₃ g	33-36	31.2	32.4	36.4		11.6	8.96-14.47
	45-48	43.4	30.3	26.3		5.6	4.04- 7.62

¹ Munsell color system. ² Samples were not taken in plow layer.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 2

Soil Type: Parnell silty clay loam

Location: A drained, nearly level depression in cropland in SW $\frac{1}{4}$ SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 1, T. 114 N., R. 42 W., 100 feet north of first telephone pole from west side of depression, Yellow Medicine County, Minn.

Parent Material: Glacial till in the upper part of profile till is sorted.
Drainage: Very Poor.

Horizon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suctions of--				Available water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	<u>In.</u>		<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./in.</u>	<u>G./cc.</u>	<u>In.</u>
Alp	0-7	Black (N 2/0) silty clay loam; cloddy; hard; neutral, pH 7.2; abrupt smooth boundary.								
Al2	7-16	Black (N 2/0) silty clay loam; moderate to strong, very fine and fine angular and subangular blocky structure; firm; neutral, pH 6.8; gradual smooth boundary.	9-12	34.6	28.1	20.3	16.5	0.130	1.12	2.08
Al3	16-25	Black (10YR 2/1) silty clay loam containing few fine distinct dark-yellowish-brown (10YR 4/4) mottles; moderate, very fine subangular blocky structure; firm, strong vertical cleavage; neutral, pH 6.8; gradual smooth boundary.	21-24	34.6	27.8	19.9	16.3	.125	1.09	
A3g	25-44	Very dark-gray (10YR 3/1) clay loam containing common medium distinct dark-yellowish-brown (10YR 4/4) mottles; weak, very fine subangular blocky structure; firm; strong vertical cleavage; mildly alkaline, pH 7.6; no reaction with HCl; gradual smooth boundary.	33-36	34.3	27.6	19.1	14.6	.161	1.24	3.06
Clg	44-58	Olive-gray (5Y 5/2) clay loam containing common fine distinct olive-brown (2.5Y 4/4) mottles; horizon examined with soil auger, structure not determined; friable, mildly alkaline, pH 7.8; no reaction with HCl; gradual smooth boundary.	45-48	39.5	31.2	21.4	15.6	.215	1.38	3.01
C2g	58-66	Olive-gray (5Y 5/2) clay loam containing many medium distinct olive-brown (2.5Y 4/4) and brown (7.5YR 4/4) mottles; friable; no reaction with HCl.	58-61	43.7	34.6	23.7	16.6	.227	1.26	.45

Horizon	Sample depth	Mechanical analyses				Hydraulic conductivity	
		Sand	Silt	Clay		Average	Range
	<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>		<u>In./hr.</u>	<u>In./hr.</u>
Alp	(²)	(²)	(²)	(²)		(²)	(²)
Al2	9-12	40.9	28.5	30.6		7.20	6.47- 7.71
Al3	21-24	38.9	26.5	34.6		22.19	7.92-48.07
A3g	33-36	43.0	28.5	28.5		15.22	9.06-25.75
Clg	45-48	26.4	40.9	32.7		4.38	1.78- 6.76
C2g	58-61	36.9	34.6	28.5		.85	.07- 2.07

¹ Munsell color system. ² Samples were not taken in plow layer.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 3

Soil Type: Vallers silty clay loam

Location: Cultivated field on a 2 percent slope 85 feet south and 85 feet west of second electric pole from corner in NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 32, T. 112 N., R. 46 W., Lincoln County, Minn.

Horizon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suction of--				Available water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	<u>In.</u>		<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./in.</u>	<u>G./cc.</u>	<u>In.</u>
Alpca	0-7	Black (10YR 2/1) light silty clay loam; cloddy; slightly firm and slightly sticky; moderately alkaline, violent effervescence; abrupt smooth boundary.	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Al2ca	7-12	Black (10YR 2/1) light silty clay loam; weak, very fine subangular blocky structure; friable; mildly alkaline, strong effervescence; clear smooth boundary.	7-10	44.5	37.0	27.6	20.8	0.165	1.02	1.98
A3gcag	12-17	Very dark-gray (2.5Y 3/1) and dark-gray (2.5Y 4/1) silty clay loam with few fine distinct dark-brown (7.5 YR 4/4) mottles; weak, very fine subangular blocky structure; friable; strong effervescence; clear smooth boundary.	14-17	37.3	30.3	22.3	17.7	.134	1.06	.67
Clcag	17-26	Mixed very dark-gray (2.3Y 3/1) dark-gray (2.5Y 4/1) and grayish-brown (2.5Y 5/2) clay loam with common fine faint-olive-brown (2.5Y 5/4) mottles; weak, very fine subangular blocky structure; friable; crayfish krotovinas noted; a few calcium sulfate crystals present; strong effervescence; diffuse smooth boundary.	20-23	37.9	30.5	21.9	17.4	.149	1.14	1.34
C2cag	26-32	Grayish-brown (2.5Y 5/2) clay loam with common medium distinct yellowish-brown (10YR 5/6) mottles; weak, very fine subangular blocky structure; friable; crayfish krotovinas noted and black manganese concretions 1 to 2 mm.; strong effervescence; gradual smooth boundary.	29-32	37.9	29.6	20.3	15.7	.172	1.24	1.03
C3g	32-60	Gray (2.5Y 5/1) clay loam containing many fine distinct light-olive-brown (2.5Y 5/6) mottles; very weak, very fine subangular blocky structure; friable; strong effervescence.	42-45	33.7	26.6	18.7	14.4	.171	1.40	4.79

Horizon	Sample depth	Mechanical analyses			Hydraulic conductivity	
		Sand	Silt	Clay	Average	Range
	<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./hr.</u>	<u>In./hr.</u>
Alpca	(2)	(2)	(2)	(2)	(2)	(2)
Al2ca	7-10	23.9	32.9	43.2	4.83	1.52- 8.08
A3gcag	14-17	22.1	32.8	45.1	14.78	5.90-26.83
Clcag	20-23	20.2	34.8	45.0	7.04	.90-10.85
C2cag	29-32	16.5	44.8	38.7	5.30	1.52-10.32
C3g	42-45	35.0	28.3	36.7	2.92	1.38- 2.63

¹ Munsell color system. ² Samples were not taken in plow layer.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 4

Soil Type: Fulda silty clay loam

Location: Cultivated field on 1 percent slope 90 feet west of first fence post south of electric pole adjacent from farm drive in NE $\frac{1}{4}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 12, T. 110 N., R. 44 W., Lincoln County, Minn.

Horizon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suctions of--				Available water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	In.		In.	Pct.	Pct.	Pct.	Pct.	In./in.	G./cc.	In.
Alp	0-8	Black (N 2/0) silty clay loam; weak, very fine angular blocky structure; slightly hard and sticky; abrupt smooth boundary.	(2)	(2)	(2)	(2)	(2)	(2)	(2)	2.18
Al2	8-13	Black (N 2/0) silty clay; moderate to strong, very fine angular blocky structure; sticky and plastic; smooth clear boundary.	9-12	40.7	35.2	27.9	21.1	0.168	1.19	
B21g	13-28	Dark-gray (5Y 4/1) silty clay; containing few fine distinct dark-yellowish-brown mottles; very dark gray (N 3/0) in upper part; moderate, very fine angular blocky structure; sticky and plastic; gradual smooth boundary.	21-24	42.6	36.8	29.0	22.1	.193	1.31	2.90
B22g	28-33	Dark-gray (5Y 4/1) and olive-gray (5Y 5/2) silty clay; containing common fine distinct dark-yellowish-brown mottles; moderate, very fine angular blocky structure; sticky and plastic; olive-gray part of horizon has weak effervescence; clear smooth boundary.	30-33	43.2	36.6	27.3	21.1	.215	1.39	1.08
B3g	33-40	Grayish-brown (5Y 5/2) silty clay; containing common medium-distinct dark-yellowish-brown mottles; moderate, very fine angular blocky structure; slightly sticky and slightly plastic; dark-yellowish-brown mottles are common, medium, and distinct; strong effervescence; clear smooth boundary.	37-40	43.0	34.8	25.4	19.5	.219	1.43	1.53
Cg	40-60	Light-olive-gray (5Y 6/2) silty clay loam; none to weak very fine subangular blocky structure; slightly sticky; pockets of calcium sulfate crystals are present along with a few soft white calcium carbonate concretions less than 5 mm.; strong effervescence.	48-51	43.5	35.0	24.5	18.1	.248	1.47	4.96

Horizon	Sample depth	Mechanical analyses			Hydraulic conductivity	
		Sand	Silt	Clay	Average	Range
	In.	Pct.	Pct.	Pct.	In./hr.	In./hr.
Alp	(2)	(2)	(2)	(2)	(2)	(2)
Al2	9-12	15.4	35.1	49.5	7.10	6.15- 8.99
B21g	21-24	13.3	35.1	51.6	6.38	4.09-10.56
B22g	30-33	11.3	35.1	53.6	5.02	3.24- 7.11
B3g	37-40	9.6	34.9	55.5	.98	.01- 2.44
Cg	48-51	10.4	34.6	55.0	1.24	.62- 2.38

¹ Munsell color system. ² Samples were not taken in plow layer.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 5

Soil Type: Parnell silty clay loam

Location: Drained depression in the west center of SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 3, T. 111 N., R. 44 W., Lincoln County, Minn.

Horizon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suctions of--				Available water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	<u>In.</u>		<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./in.</u>	<u>G./cc.</u>	<u>In.</u>
Alp	0-12	Black (N 2/0) silty clay loam; cloddy; firm and sticky; weak plow sole at lower part of horizon; mildly alkaline, pH 7.5; no reaction with HCl; abrupt smooth boundary.	(²)	(²)	(²)	(²)	(²)	(²)	(²)	3.48
Al2	12-24	Black (N 2/0) silty clay loam; weak, very fine subangular blocky structure; friable; neutral, pH 7.2; gradual smooth boundary.	12-15	33.8	27.6	20.6	16.8	0.145	1.34	
A3g	24-34	Very dark-gray (N 3/0) silty clay loam with few fine distinct, very dark-grayish-brown (10YR 3/2) mottles; weak coarse and very fine subangular blocky structure; sticky and plastic; neutral, pH 7.2; gradual smooth boundary.	24-27	34.2	26.6	18.1	15.6	.161	1.46	
Clg	34-40	Very dark-gray (N 3/0) and olive-gray (5Y 4/2 5/2) silty clay loam with few fine distinct dark-yellowish-brown (10YR 4/4) mottles; weak, very fine and fine subangular blocky structure; sticky; neutral, pH 7.2; gradual smooth boundary.	34-37	33.7	26.0	17.2	13.5	.175	1.40	1.05
C2g	40-60	Gray (5Y 5/1) silty clay loam with common medium distinct light-olive-brown (2.5Y 5/4) mottles; horizon examine with auger; sticky; mildly alkaline, pH 7.4; weak effervescence at 54 inches.	42-45	34.2	26.3	17.4	13.7	.173	1.37	1.38
			51-54	34.5	26.8	18.1	13.1	.207	1.51	2.48

Horizon	Sample depth	Mechanical analyses			Hydraulic conductivity	
		Sand	Silt	Clay	Average	Range
	<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./hr.</u>	<u>In./hr.</u>
	(²)	(²)	(²)	(²)	(²)	(²)
Alp	12-15	36.7	24.5	38.8	0.77	0.25-1.65
Al2	24-27	43.1	17.2	39.7	4.12	.19-7.78
A3g	34-37	43.1	26.4	30.5	7.19	5.40-8.49
Clg	42-45	49.5	26.3	24.2	3.67	1.49-5.67
C2g	51-54	43.4	26.3	30.3	2.97	.67-6.77

¹ Munsell color system.² Samples were not taken in plow layer.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 6

Soil Type: Flom silty clay loam

Location: Cropland on a 1 percent slope 80 feet north of railroad tracks and 110 feet east of road edge in the NW¹₄SW¹₄NW¹₄ sec. 4, T. 109 N., R. 46 W., Lincoln County, Minn.

Hori- zon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suctions of--				Avail- able water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	<u>In.</u>		<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./in.</u>	<u>G./cc.</u>	<u>In.</u>
Alp	0-6	Black (N/2 to 10YR 2/1) silty clay loam; cloddy to weak, very fine subangular blocky structure; friable and slightly sticky; no reaction with HCl; abrupt smooth boundary.	(²)	(²)	(²)	(²)	(²)	(²)	(²)	2.35
Al2	6-13	Black (N2/0 to 10YR 2/1) silty clay loam; moderate, very fine and fine subangular blocky structure; friable; no reaction with HCl; clear smooth boundary.	9-12	36.8	30.8	23.1	16.2	0.181	1.24	
A3g	13-17	Very dark-gray (N3/0 to 10YR 3/1) silty clay loam with a few olive-brown (2.5Y 4/4) worm casts and a few fine distinct dark-yellowish-brown (10YR 4/4) mottles; weak, very fine subangular blocky structure; friable; olive-brown casts have slight effervescence; clear irregular boundary.	14-17	34.6	27.6	19.6	14.2	.182	1.36	.73
B2g	17-21	Very dark-grayish-brown (2.5Y 3/2) silty clay loam containing about 20 percent very dark-gray (10YR 3/1) worm casts and common fine distinct dark-yellowish-brown (10YR 4/4) mottles; weak, very fine subangular blocky structure; friable, slight effervescence; clear wavy boundary.	18-21	32.2	26.4	18.6	12.6	.193	1.40	.77
Clg	21-30	Grayish-brown (2.5Y 5/2) clay loam containing common medium distinct dark-yellowish-brown (10YR 4/4) mottles; weak, very fine subangular structure; friable; strong effervescence; gradual smooth boundary.	27-30	27.3	21.4	13.9	10.2	.168	1.48	1.51
C2gca	30-60	Gray (5Y 6/1) clay loam containing many coarse distinct yellowish-brown (10YR 5/6) mottles; very weak, very fine subangular blocky structure; friable; few 1- to 3-mm. round black manganese concretions; few soft white calcium carbonate concretions in lower part of horizon; strong effervescence.	42-45	30.9	24.4	17.0	11.1	.202	1.52	6.06

Horizon	Sample depth	Mechanical analyses			Hydraulic conductivity	
		Sand	Silt	Clay	Average	Range
	<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./hr.</u>	<u>In./hr.</u>
Alp	(²)	(²)	(²)	(²)	(²)	(²)
Al2	9-12	32.7	30.6	36.7	5.55	1.32-11.82
A3g	14-17	28.8	32.6	38.6	1.69	.61- 3.63
B2g	18-21	30.7	32.6	36.7	3.03	.88- 5.49
Clg	27-30	41.3	24.3	34.4	4.42	3.15- 7.83
C2gca	42-45	37.7	26.1	36.2	3.32	2.05- 5.79

¹ Munsell color system. ² Samples were not taken in plow layer.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 7

Soil Type: Lamoure silty clay loam

Location: Cropland in a nearly level bottomland 20 feet west and 25 feet north of corner fence post in the SE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 4, T. 109 N., R. 46 W., Lincoln County, Minn.

Horizon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suctions of--				Available water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	<u>In.</u>		<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./in.</u>	<u>G./cc.</u>	<u>In.</u>
Alp	0-11	Very dark-gray (10YR 3/1) silty clay loam; cloddy; slightly sticky; slight effervescence; abrupt smooth boundary.	(2)	(2)	(2)	(2)	(2)	(2)	(2)	3.33
Al2	11-17	Black (10YR 2/1) silty clay loam; weak, very fine subangular blocky structure; friable; strong effervescence; gradual smooth boundary.	11-14	50.9	41.1	29.2	21.3	0.196	0.99	
Al3	17-34	Black (N 2/0) silty clay loam; moderate, very fine subangular blocky structure; friable strong effervescence; clear smooth boundary.	18-21	48.3	37.8	26.4	17.5	.221	1.09	1.11
			27-30	44.3	32.9	20.1	14.0	.244	1.29	2.93
A3	34-60	Very dark-gray (5Y 3/1) and gray (5Y 5/1) silty clay loam; weak, very fine and fine subangular blocky structure; friable; violent effervescence.	34-37	41.3	30.3	18.6	13.8	.226	1.37	2.26
			48-51	38.0	27.8	16.6	11.3	.239	1.45	3.82

Horizon	Sample depth	Mechanical analyses			Hydraulic conductivity	
		Sand	Silt	Clay	Average	Range
	<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./hr.</u>	<u>In./hr.</u>
Alp	(2)	(2)	(2)	(2)	(2)	(2)
Al2	11-14	20.3	47.0	32.7	4.08	0.22-10.23
Al3	18-21	20.3	47.0	32.7	.33	.07- .61
	27-30	21.7	45.8	32.5	.91	.48- 1.66
A3	34-37	32.9	38.6	28.5	5.79	.83-12.54
	48-51	37.0	36.6	26.4	5.91	.26-10.17

¹ Munsell color system. ² Samples were not taken in plow layer.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 8

Soil Type: Flom clay loam
 Location: In cropland 150 feet west of north-south fence line and 25 feet north of field border in the SW $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 6, T. 114 N., R. 41 W., Yellow Medicine County, Minn.

Parent Material: Glacial till of Mankato substage.
 Classification: Humic Gley.
 Drainage: Poor.

Horizon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suction of--				Available water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	<u>In.</u>		<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./in.</u>	<u>G./cc.</u>	<u>In.</u>
Alp	0-7	Black (N 2/0) clay loam; cloddy; friable and sticky; no reaction with HCl; mildly alkaline, pH 7.6; clear smooth boundary.	(²)	(²)	(²)	(²)	(²)	(²)	(²)	2.41
Al2	7-14	Black (N 2/0) clay loam; weak, very fine and fine subangular blocky structure; sticky; no reaction with HCl; mildly alkaline, pH 7.8; clear smooth boundary.	9-12	38.2	32.2	24.4	17.6	0.172	1.18	
A3	14-18	Very dark-gray (N 3/0) and gray (5Y 5/1) clay loam; weak to moderate, very fine subangular blocky structure; sticky; spots have slight effervescence; moderately alkaline; clear wavy boundary.	15-18	39.4	32.8	24.2	17.3	.194	1.25	.78
Clgca	18-28	Gray (5Y 5/1) clay loam containing common medium distinct light-olive-brown (2.5Y 5/6) mottles and a few very dark-gray (N 3/0) casts; weak fine and medium subangular blocky structure; sticky, strong effervescence; clear smooth boundary.	21-24	38.0	31.4	22.8	15.2	.217	1.34	2.17
C3gca	34-60	Light-olive-gray (5Y 6/2) clay loam containing many coarse distinct light-olive-brown (2.5YR 5/4) mottles and a few medium prominent yellowish-red (5YR 4/8) mottles; structure not determined as horizon was examined with soil auger; sticky; few white soft and hard calcium carbonate concretions present; strong and violent effervescence.	34-37	35.7	28.8	20.3	14.4	.207	1.44	2.90
			45-48	34.2	27.6	19.2	13.9	.207	1.51	3.73

Horizon	Sample depth	Mechanical analyses			Hydraulic conductivity	
		Sand	Silt	Clay	Average	Range
	<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./hr.</u>	<u>In./hr.</u>
Alp	(²)	(²)	(²)	(²)	(²)	(²)
Al2	9-12	40.5	26.7	32.8	3.02	0.31-8.12
A3	15-18	40.5	22.6	36.9	.04	.02- .06
Clgca	21-24	38.7	22.5	38.8	.08	.02- .11
C3gca	34-37	40.9	26.5	32.6	.85	.11-1.57
	45-48	38.9	30.6	30.5	1.44	.85-1.89

¹ Munsell color system. ² Samples were not taken in plow layer.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 9

Soil Type: 211 (Dovray)

Location: 10 feet east and 30 feet south of electric pole
of SW $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 14, T. 114 N., R. 41 W., Yel-
low Medicine County, Minn.

Parent Material: Lacustrine silts and clays.

Classification: Humic Gley.

Drainage: Very poor.

Hori- zon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suction of--				Avail- able water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	<u>In.</u>		<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./in.</u>	<u>G./cc.</u>	<u>In.</u>
Alp	0-6	Black (N 2/0) silty clay; cloddy; very sticky when wet; mildly alkaline, pH 7.4; abrupt smooth boundary.	(²)	(²)	(²)	(²)	(²)	(²)	(²)	2.02
Al2g	6-12	Black (N 2/0) silty clay; weak, very fine angular blocky structure; very sticky when wet; slightly compacted; neutral, pH 7.1; clear smooth boundary.	9-12	55.6	43.2	37.2	26.1	0.168	0.98	
A3g	12-21	Very dark gray (N 3/0) to gray (5Y 3/1) silty clay containing common fine distinct yellowish-brown (10YR 5/6) mottles; moderate, very fine angular blocky structure; very sticky when wet; neutral, pH 7.0; gradual smooth boundary.	18-21	57.2	49.4	38.9	28.2	.216	1.09	
Bg	21-42	Dark-gray (5Y 4/1) heavy silty clay containing common fine distinct yellowish-brown (10YR 5/6) mottles; moderate to strong, very fine angular blocky structure slightly larger peds than in horizon above; very sticky when wet; neutral, pH 6.9; diffuse smooth boundary.	33-36	62.3	52.6	39.9	30.1	.263	1.17	5.52
B-Clg	42-54	Dark-gray (5Y 4/1) to gray (5Y 5/1) silty clay containing common medium distinct yellowish-brown (10YR 5/6) mottles; structure, if any, not determined; very sticky when wet; no effervescence; clear smooth boundary.	45-48	62.7	54.7	43.0	29.6	.254	1.01	3.05
IIC2g	54-60	Greenish-gray (5BG 5/1) silty clay loam and grayish-green (5G 4/2), very fine sandy loam containing common coarse prominent strong-brown (7.5YR 5/8) mottles; structure, if any, not determined; sands and silty clays are stratified; strong effervescence.	55-58	56.6	47.4	35.8	24.9	.243	1.08	1.46

Horizon	Sample depth	Mechanical analyses			Hydraulic conductivity	
		Sand	Silt	Clay	Average	Range
	<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./hr.</u>	<u>In./hr.</u>
Alp	(²)	(²)	(²)	(²)	(²)	(²)
Al2g	9-12	9.3	33.0	57.7	0.07	0.00-0.14
A3g	18-21	13.1	20.7	66.2	.08	.03- .15
Bg	33-36	10.8	16.6	72.6	.07	.05- .10
B-Clg	45-48	8.2	18.8	73.0	3.86	2.54-4.22
IIC2g	55-58	10.5	48.8	40.7	.87	.77-1.05

¹ Munsell color system. ² Samples were not taken in plow layer.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 10

Soil Type: 57 (unnamed silty clay loam)

Location: Cropland 75 feet east of third electric pole,
north of west center of section in SW $\frac{1}{4}$ NW $\frac{1}{4}$ SW $\frac{1}{4}$
sec. 15, T. 118 N., R. 43 W., Lac qui Parle
County, Minn.

Parent Material: Clayey waterlaid sediments probably of
Glacial River Warren origin.

Classification: Humic Gley.

Drainage: Very gently undulating.

Hori- zon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at sections of--				Avail- able water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	In.		In.	Pct.	Pct.	Pct.	Pct.	In./in.	G./cc.	In.
Alp	0-6	Black (10YR 2/1) silty clay loam; weak, very fine subangular blocky structure; friable and sticky; slightly acid, pH 6.4; abrupt smooth boundary.	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Al2	6-16	Black (10YR 2/1) grading to very dark-gray (10YR 3/1) silty clay; very dark-gray (10YR 3/1) when crushed; moderate to strong, very fine angular blocky structure; firm; neutral, pH 6.6; clear smooth boundary.	9-12	48.3	41.8	33.1	24.7	0.197	1.15	3.15
A3g	16-24	Very dark-gray (N 3/0) silty clay contain- ing few fine distinct dark-yellowish-brown (10YR 4/4) mottles; moderate, very fine angular blocky structures; firm; pinholes less than 1 mm. common; neutral, pH 6.6; gradual wavy boundary.	18-21	51.5	44.8	35.7	26.9	.224	1.25	1.79
B2g	24-39	Olive-gray (5Y 4/2) and dark-gray (5Y 4/1) silty clay; gray (5Y 5/1) when crushed; weak to moderate, very fine and fine angu- lar blocky structure; firm; thin continuous clay films or shiny pressure faces on sur- faces of peds; tongues of a horizon mate- rial extend into horizon; few hard red iron concretions in lower part; few fine pin- holes less than 1 mm.; mildly alkaline, pH 7.4; clear wavy boundary.	30-33	54.3	47.3	38.0	29.7	.229	1.30	3.44
Clgca	39-46	Gray (5Y 5/1) silty clay loam containing common medium distinct brown (7.5 YR 4/4) mottles; very weak fine and medium sub- angular blocky structure; firm; horizon has 1-inch-thick band high in dark- yellowish-brown (10YR 4/4) iron concre- tions; horizon also has a few soft white calcium carbonate concretions; mildly alka- line, pH 7.8; slight and strong efferves- cence; clear smooth boundary.	40-43	55.5	47.0	36.3	28.4	.240	1.29	1.68
C2gca	46-52	Light-brownish-gray (5Y 6/2) light silty clay loam containing common medium distinct brown (7.5YR 4/4) mottles; horizon examined with soil auger; friable; strong efferves- cence; clear smooth boundary.	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
C3g	52-60	Dark-gray (5Y 4/1) silty clay loam con- taining common medium-distinct brown (7.5YR 4/4) mottles; firm; strong effervescence.	52-55	57.8	48.8	37.9	30.3	.228	1.23	3.19

Horizon	Sample depth	Mechanical analyses				Hydraulic conductivity	
		Sand	Silt	Clay		Average	Range
	In.	Pct.	Pct.	Pct.		In./hr.	In./hr.
Alp	(2)	(2)	(2)	(2)		(2)	(2)
Al2	9-12	12.4	27.8	59.8		1.18	0.22-2.85
A3g	18-21	11.2	28.9	59.9		.03	.00-.07
B2g	30-33	11.1	24.8	64.1		.02	.01-.02
Clgca	40-43	11.0	18.6	70.4		.02	.01-.04
C2gca	52-55	11.6	24.7	63.7		.04	0-.09
C3g							

¹ Munsell color system. ² Samples were not taken in plow layer. ³ No sample obtained.

Soil Profile Descriptions and Soil Moisture Retention Data

Sample Site 11

Soil Type: 211 (Dovray) silty clay loam

Location: In cropland 25 feet west of field border adjacent to fourth electric pole from northeast corner of section on opposite side of road in SE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 22, T. 110 N., R. 43 W., Lac qui Parle County, Minn.

Parent Material: Clayey waterlaid sediments probably of

Glacial River Warren origin.

Classification: Humic Gley.

Drainage: Very poor.

Horizon	Depth	Profile description ¹	Sample depth	Water content (dry weight) at suction of--				Available water	Bulk density	Available water in horizon
				0.1 bar	0.33 bar	2 bars	15 bars			
	<u>In.</u>		<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./in.</u>	<u>G./cc.</u>	<u>In.</u>
Alp	0-10	Black (N 2/0) heavy silty clay loam; cloddy; hard; no reaction with HCl; mildly alkaline, pH 7.4; clear smooth boundary.	(²)	(²)	(²)	(²)	(²)	(²)	(²)	3.36
Al2	10-33	Black (N 2Y) silty clay containing few fine distinct dark-yellowish-brown (10YR 4/4) mottles; moderate, very fine angular blocky structure; firm; few threads of calcium sulphate in upper part of horizon; no reaction with HCl; mildly alkaline, pH 7.7; gradual smooth boundary.	10-13 24-27	47.0 49.2	39.3 40.9	29.6 30.2	22.4 23.2	0.210 .234	1.24 1.32	
A3g	33-43	Very dark-gray (5Y 3/1) silty clay; weak to moderate, very fine angular blocky structure; firm; peds have shiny faces due to clay films or pressure faces; no reaction with HCl; moderately alkaline, pH 7.9; gradual smooth boundary.	35-38	50.2	42.3	32.0	24.7	.236	1.34	2.36
BC1g	43-56	Olive-gray (5Y 5/2) heavy silty clay loam containing many medium distinct brown (7.5 YR 4/4) and dark-yellowish-brown (10YR 4/4) mottles; structure not determined as horizon was sampled with soil auger; firm; no reaction with HCl; moderately alkaline; clear boundary.	45-48	49.8	41.4	31.3	25.0	.221	1.35	2.87
C2g	56-60	Light-olive-gray (5Y 6/2) silty clay containing many fine distinct dark-yellowish-brown (10YR 4/4) mottles; firm; slight and strong effervescence; moderately alkaline.	57-60	56.0	47.4	36.1	26.2	.261	1.23	1.04

Horizon	Sample depth	Mechanical analyses			Hydraulic conductivity	
		Sand	Silt	Clay	Average	Range
	<u>In.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>In./hr.</u>	<u>In./hr.</u>
Alp	(²)	(²)	(²)	(²)	(²)	(²)
Al2	10-13	15.8	34.9	49.3	0.21	0.03-0.49
	24-27	11.7	30.8	57.5	.01	0 - .02
A3g	35-38	10.0	30.0	60.0	.01	0 - .01
BC1g	45-48	9.7	32.8	57.5	.99	.01-2.89
C2g	57-60	9.7	28.7	61.6	.02	.01- .02

¹ Munsell color system. ² Samples were not taken of plow layer.

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